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Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Three-Dimensional Flow Modeling of McNary Dam Forebay, Columbia River

E. Allen Hammack and David S. Smith

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Final report

Abstract

The U.S. Army Corps of Engineers, Walla Walla District (NWW), requested that the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL) model the flow conditions of McNary Dam forebay. The different flows are produced by various powerhouse/spillbay operating conditions for certain river discharges. The flow conditions, powerhouse operation schedule, and spillbay opening geometry were provided by NWW. This report contains a description of the geometry, meshing, and the flow conditions.

The report also describes flow solutions obtained using the commercial flow code Fluent. Fifteen river discharge/powerhouse/spillbay operations were included in the analysis. Figures of the flow velocity, acceleration, and strain rate near each powerhouse unit and spillbay have been provided to NWW electronically.

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Preface

The investigation described in this report was sponsored by U.S. Army Corps of Engineers, Walla Walla District (NWW) and the Navigation Systems Research Program (NSRP). This work was completed at the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC) between July 2010 to November 2011.

This research was conducted under the general direction of Dr. William D. Martin, Director of CHL; Jose E. Sanchez, Deputy Director of CHL; Dr. Rose Kress, Chief of the Navigation Division, CHL; and Dr. Richard Styles, Chief of the Navigation Branch, CHL.

The investigation and report was completed by E. Allen Hammack and David S. Smith of the Navigation Branch, CHL. The report was peer reviewed by Dr. Richard L. Stockstill, Navigation Branch, CHL. Acknowledgements are made to Charles E. Wiggins, Navigation Systems Research Program Manager and Jeff Lillycrop, Technical Director for Navigation, ERDC.

At the time of this report, COL Kevin J. Wilson was the Commander and Executive Director of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters

1 Background

McNary Dam is located at River Mile 292.0 of the Columbia River and has been in service since 1957. The normal operating pool is el 335.0-340.0 with a maximum pool elevation of 356.5. McNary Dam has fourteen 70-MW powerhouse units. The 1310-ft spillway is comprised of twenty-two spillbays. Temporary spillway weirs (TSWs) are commonly used to help fish safely navigate the dam. Figure 1 shows a plan view of the tailrace and the dam and powerhouse. Each spillbay is labeled “S,” and each powerhouse unit is labeled “PH.”

Figure 1. Plan view of McNary Dam Forebay showing the spillbays and powerhouse units.

This study focuses on the hydraulic differences near the structure caused by altering the powerhouse operation schedule. The powerhouse and spillway significantly alter the flow behavior immediately upstream of the structure. The operating powerhouse units draw flow toward the river bed and into the intakes. The open spillway bays draw flow toward the water surface. These stimuli create complex 3-D flow patterns that can be captured with 3-D numerical models. Extensive modeling efforts have been made to ensure that new powerhouse and spillway operations do not negatively impact the passage behavior of fish causing migration delays. The U. S. Army Corps of Engineers, Walla Walla District (NWW), requested the modeling of fifteen operations to determine the hydraulic effects near the structure. The fifteen operations encompass flow conditions experienced throughout a typical spring and summer. Additionally, these flow solutions were to be used in support of a numerical fish behavior modeling study to be performed by U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL).

2 Geometry

NWW provided a 3-D CAD model that included the bathymetry, the structure, and the water-surface profile. Model testing performed by NWW revealed that changes to powerhouse operation and spillbay gate openings affect the flows within about 3700 ft upstream of the structure. Therefore, the upstream boundary of the flow domain was placed 5000 ft upstream of the structure to allow an appropriate flow distribution to develop before interacting with project operations near the dam. The flows in the relatively shallow regions (less than 10 ft deep) – near the banks of the river – were insignificant to the focus of this study, so they were excluded from the flow domain. The surface geometry without the water surface is shown in Figure 2. The bathymetry is shown in yellow, the structure is shown in gray, and the inflow boundary is shown in green.

The powerhouse units are number left to right looking downstream (Figure 1). Each powerhouse unit is composed of three inlets. A section of the powerhouse showing five of the units is shown in Figure 3.

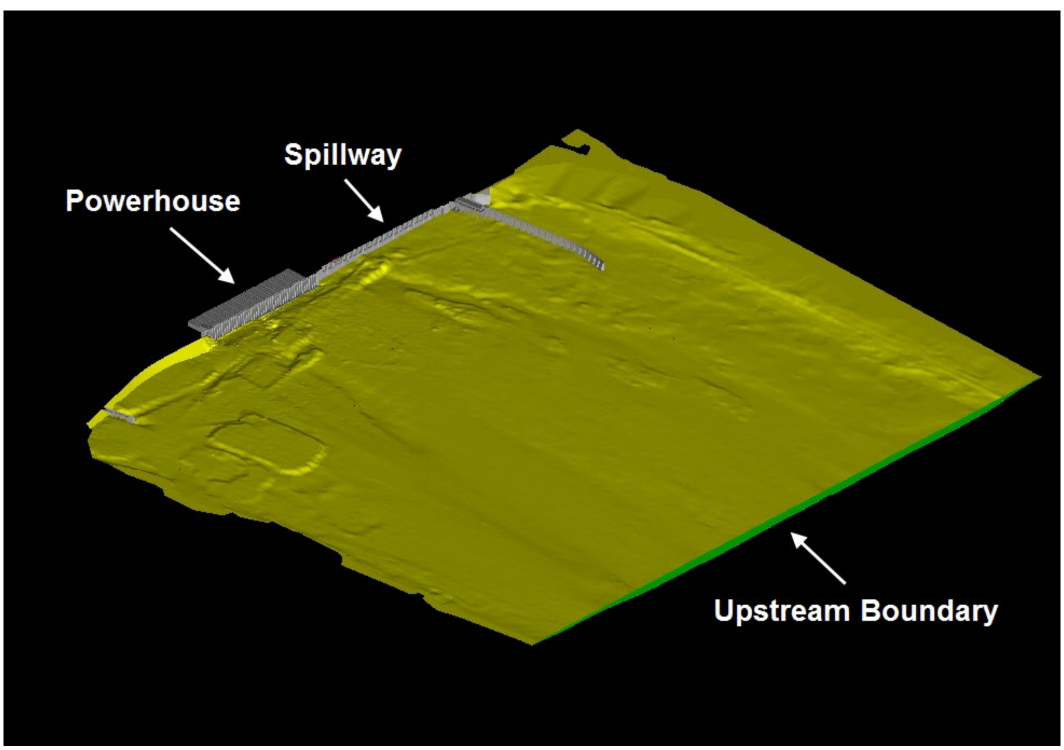

Figure 2. McNary Surface Geometry

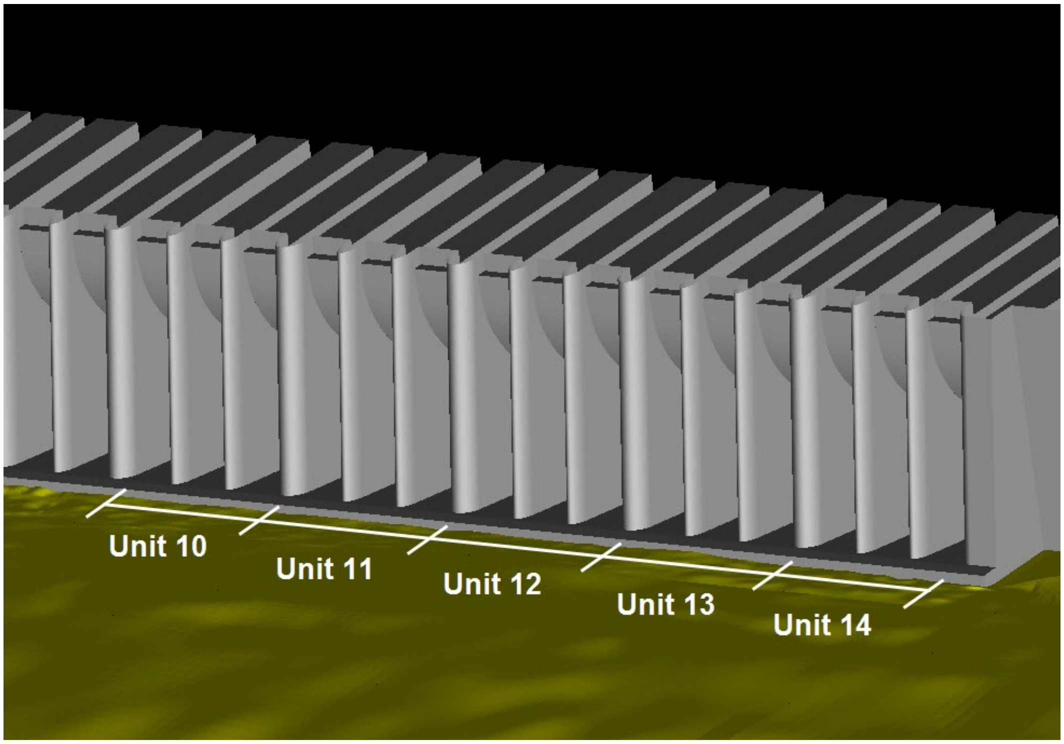

Figure 3. Powerhouse intake surface geometry.

Each powerhouse unit intake inlet is 20 ft long by 40 ft tall. The inlets are 7 ft apart. A cross-section of a powerhouse unit is shown in Figure 4. Looking downstream, each powerhouse unit inlet is labeled left to right as Inlets A, B, and C.

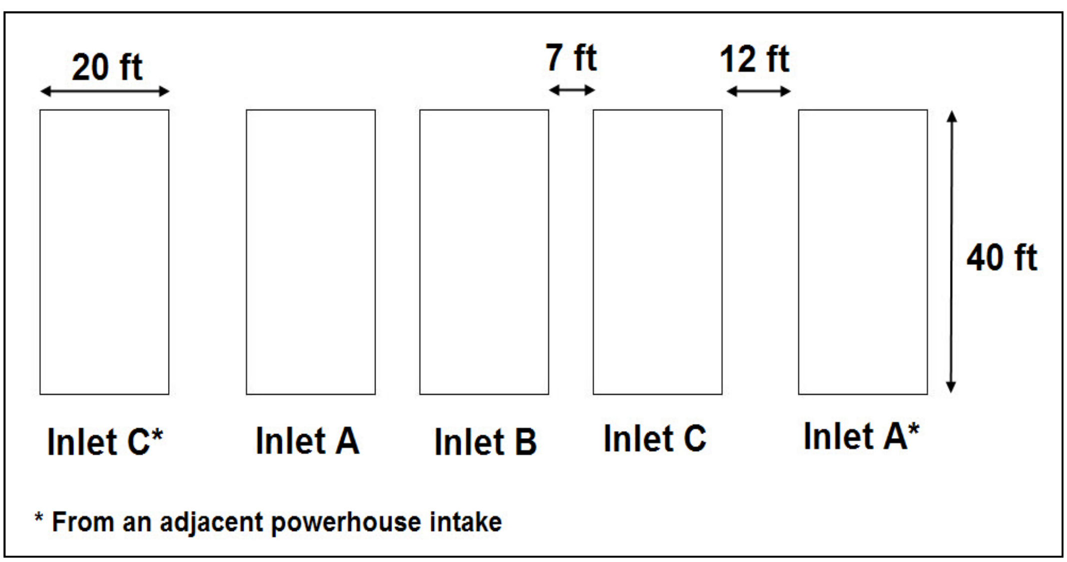

Figure 4. Powerhouse unit intake inlet description.

The powerhouse intakes (shown in red in Figure 5) were extended 200 ft downstream of the roof curve to ensure that flow exiting the powerhouse was normal to the boundary. The spillway bays are numbered right to left looking downstream (Figure 1). Each spillbay is 50 ft wide, and a 10-ft pier separates each one. The spillbay gate openings specified for each flow operation are listed in each Input Summary section. A section of the flow domain with both open and closed spillbays is shown in Figure 6. The red surfaces indicate the spillbay gate opening.

Spring operations included temporary spillbay weirs (TSWs) on two gates with a water-surface drawdown induced by the TSWs incorporated into the geometry. The drawdown water-surface profile for the 338.5 pool elevation was not provided, so a profile was determined by interpolating physical model profiles for forebay elevations of 337.0 and 340.0 provided by NWW. The lateral water-surface drawdown was assumed to extend over one spillbay width on each side of the TSW. The modified water-surface profile accounting for the TSW drawdown is shown in Figure 7. The water-surface profile at the TSW is shown in Figure 8. Summer operation used a fixed water surface at el 338.5 and did not include TSWs.

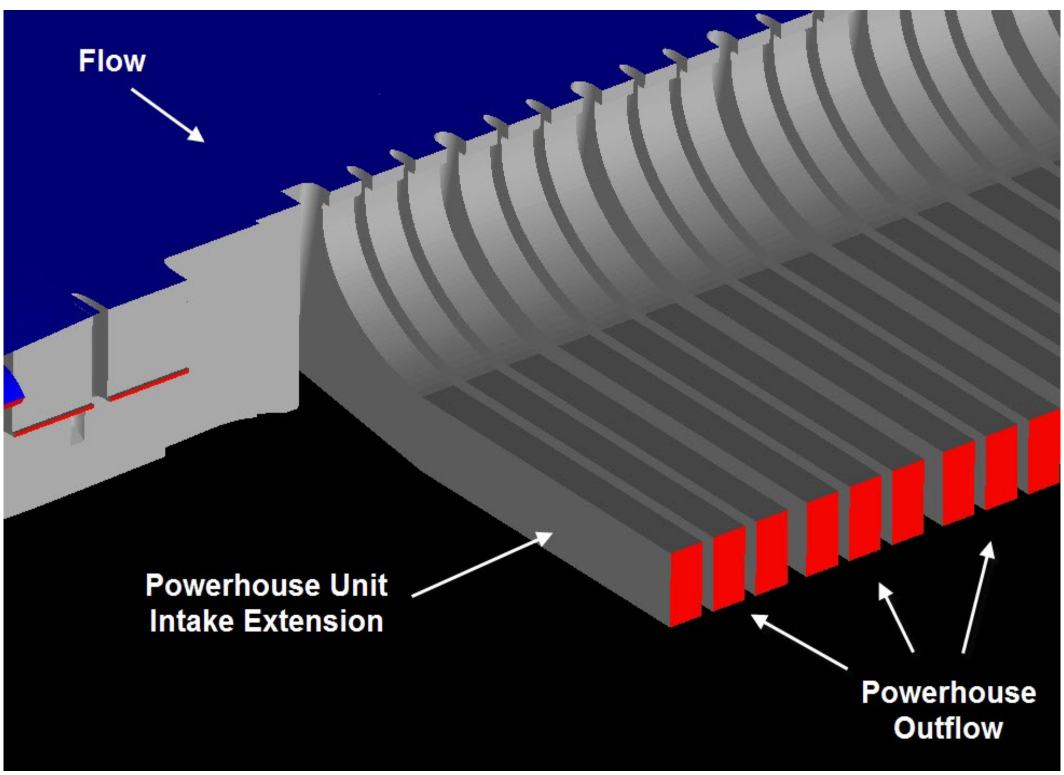

Figure 5. Surface geometry – powerhouse unit intake expansion.

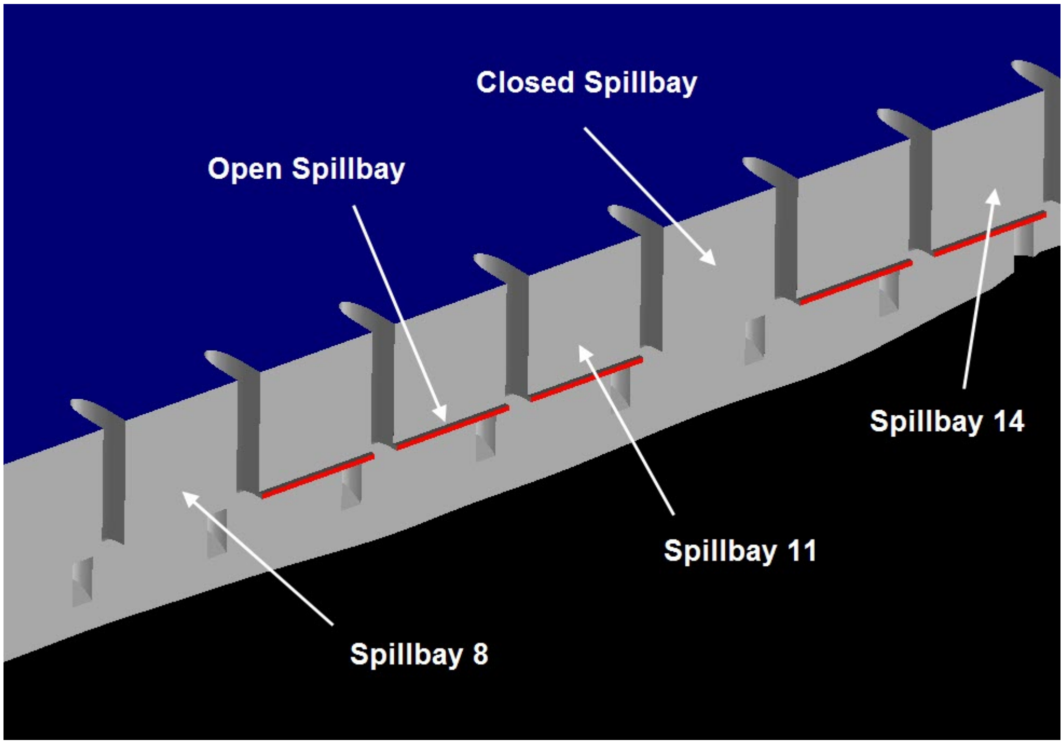

Figure 6. Surface geometry – open and closed spillbays.

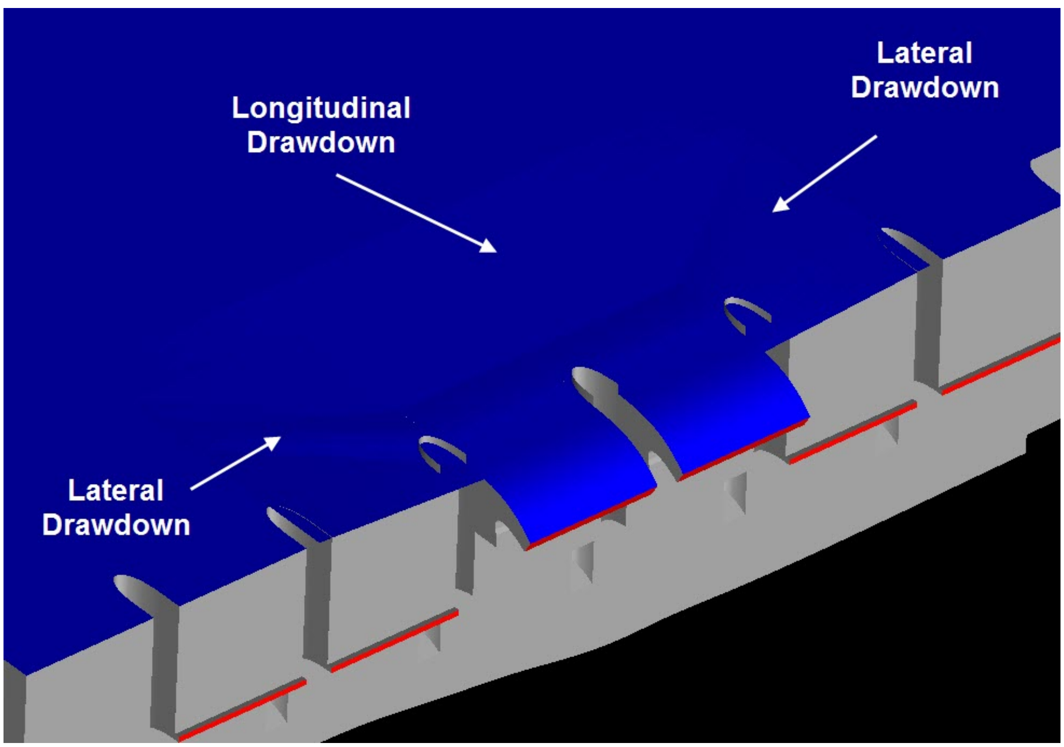

Figure 7. Water-surface drawdown due to TSWs used for operations 9-15.

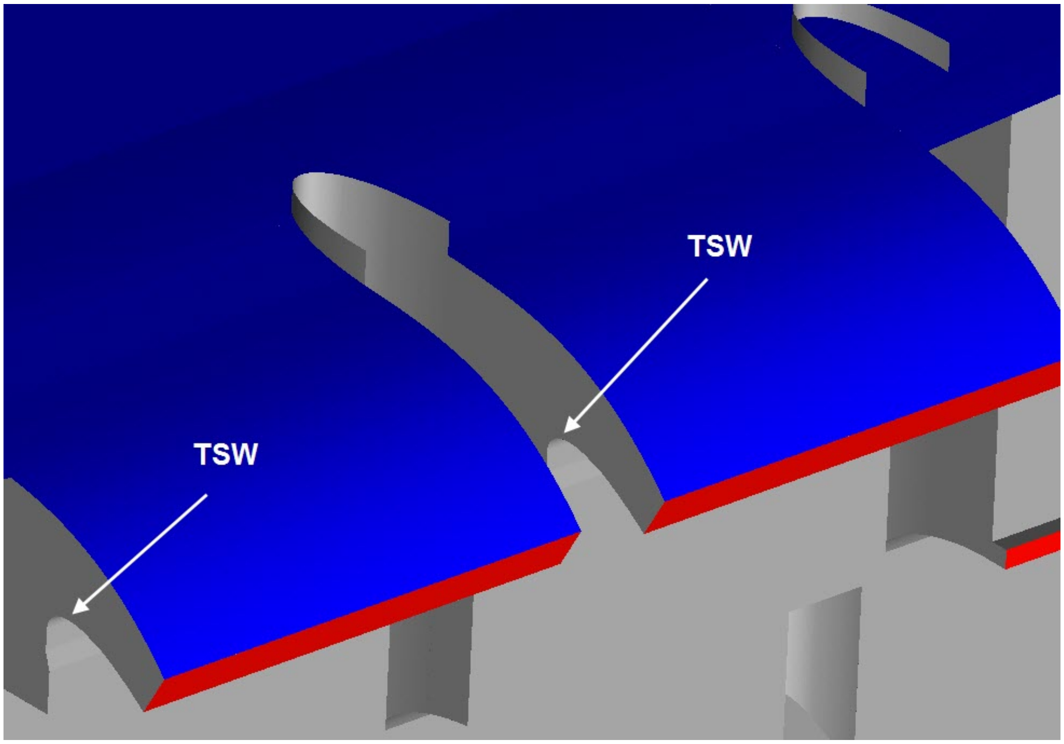

Figure 8. Water-surface profile at a TSW.

3 Computational Meshing

The focus of the hydrodynamic modeling is the behavior of the flow near the structure, so the mesh resolution was higher in those areas. Cells within 100 ft of the face of the dam have approximate side lengths of 3 ft. Further from the structure the cell size was increased to 23 ft nominal side lengths. Within the powerhouse intakes, the mesh cell sides were about 7 ft long. The spillbay gate openings were much smaller relative to the other lengths in the flow domain. Therefore, the smallest cells – with nominal side lengths of 0.5 ft – are found on the outflow boundaries of each spillbay. The mesh resolution at various locations within the mesh is shown in Figures 9-16.

The meshes for each proposed operation have between 1.2 and 1.3 million nodes and between 6.2 and 6.6 million volume cells. Table 1 shows the number of nodes and cells in each mesh.

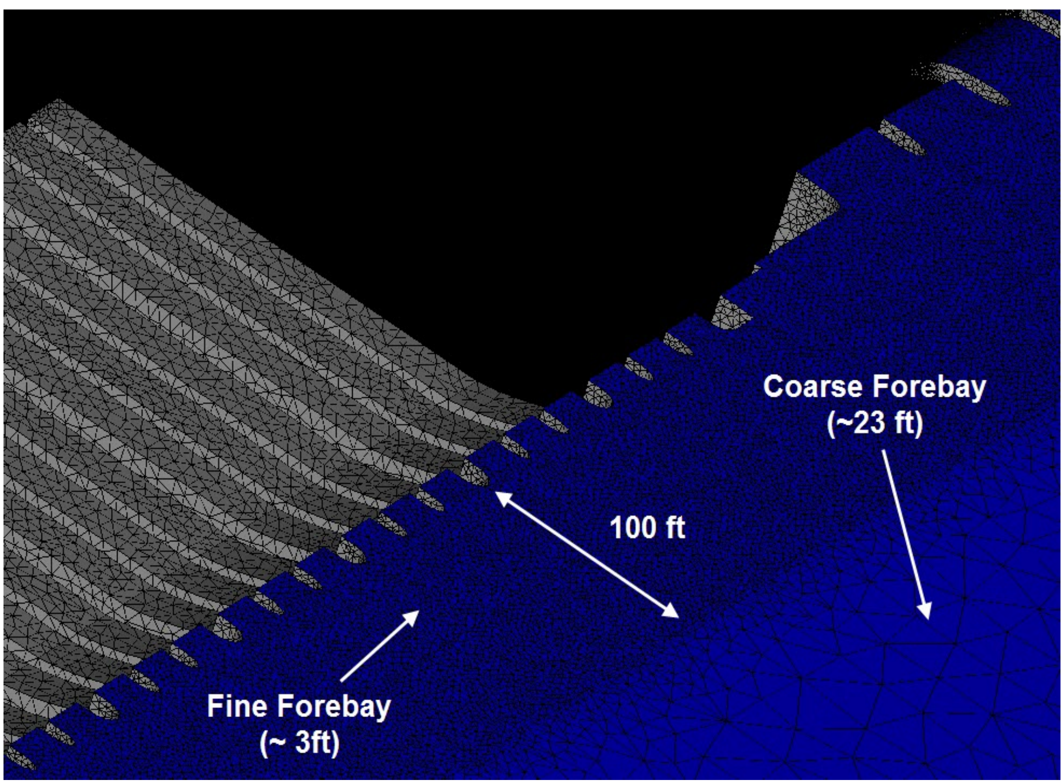

Figure 9. Mesh resolution in the forebay near the dam.

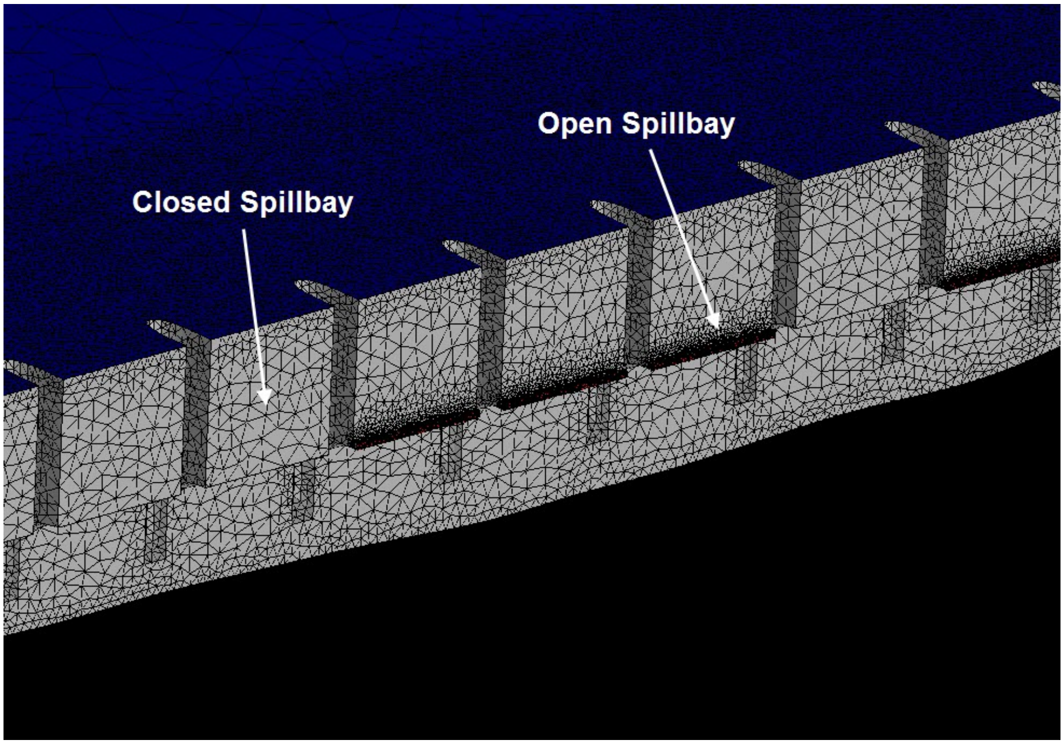

Figure 10. Spillway mesh resolution.

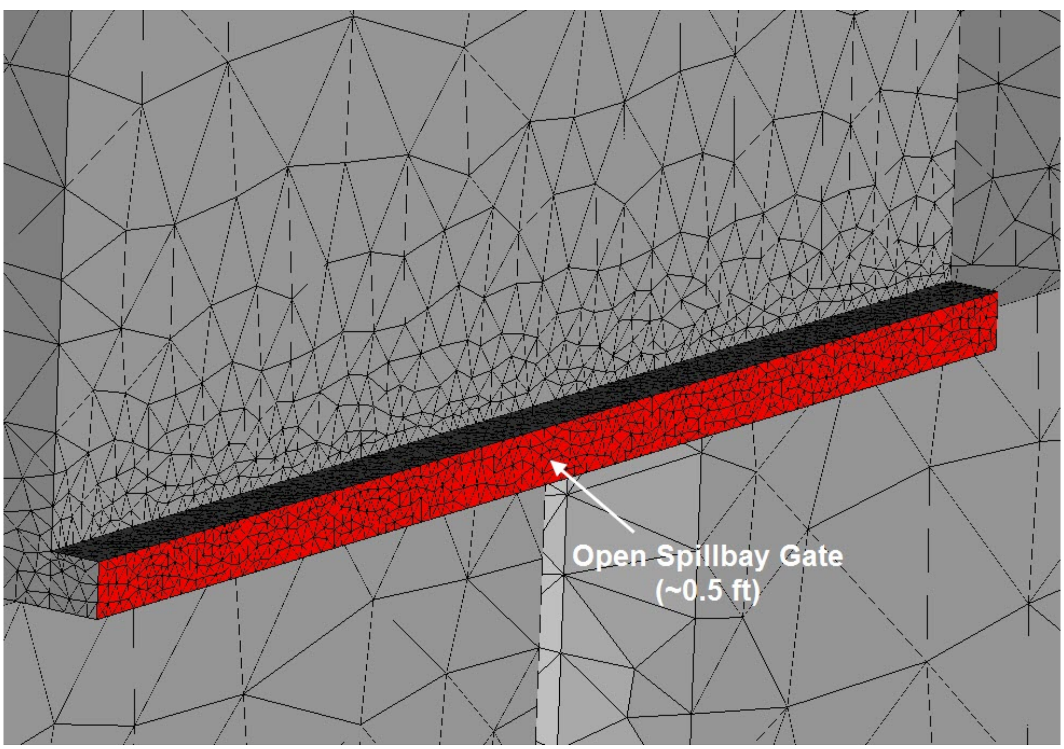

Figure 11. Mesh detail for an open spillway.

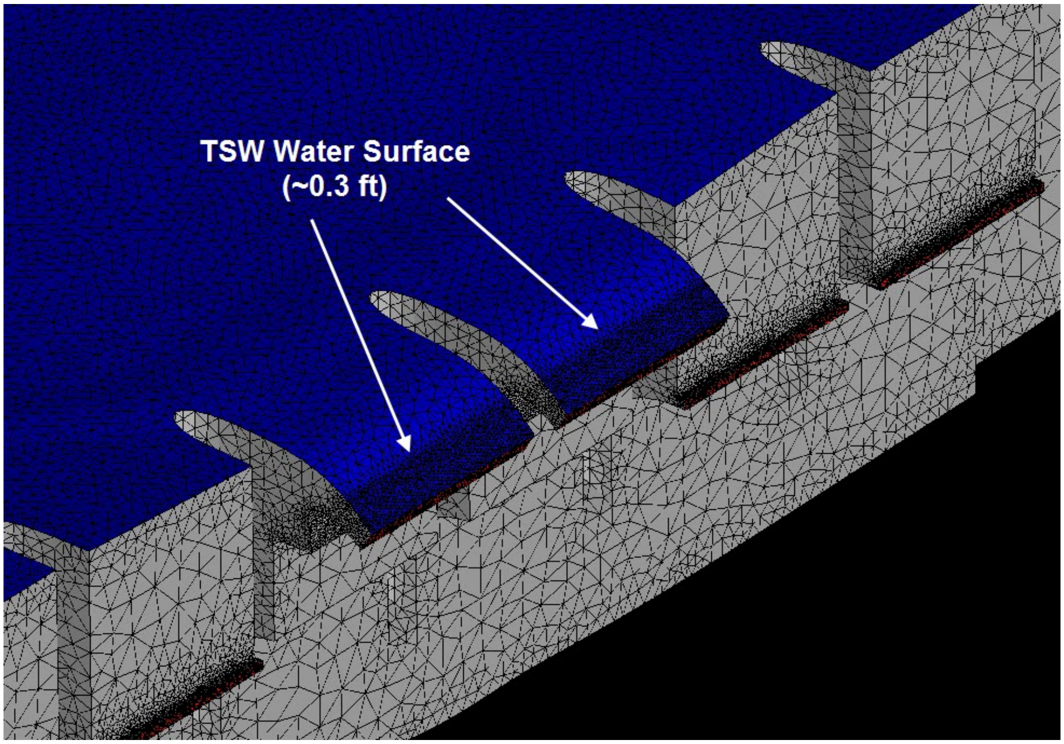

Figure 12. Mesh detail of the water-surface drawdown induced by the TSWs.

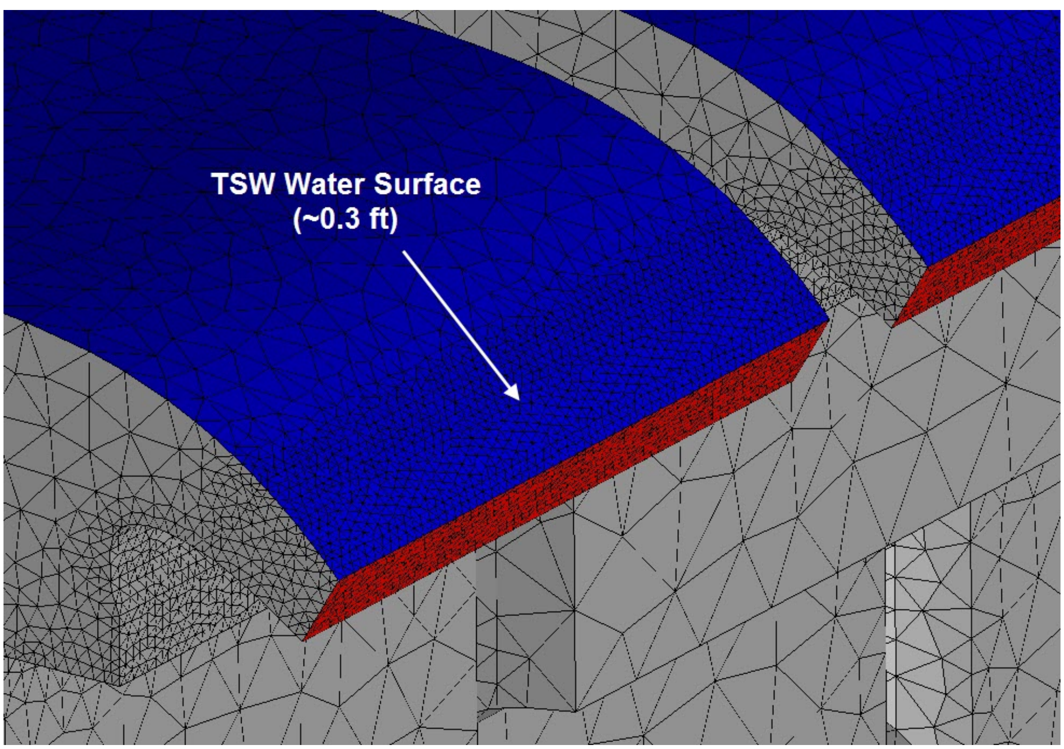

Figure 13. Mesh detail of flow over the TSW.

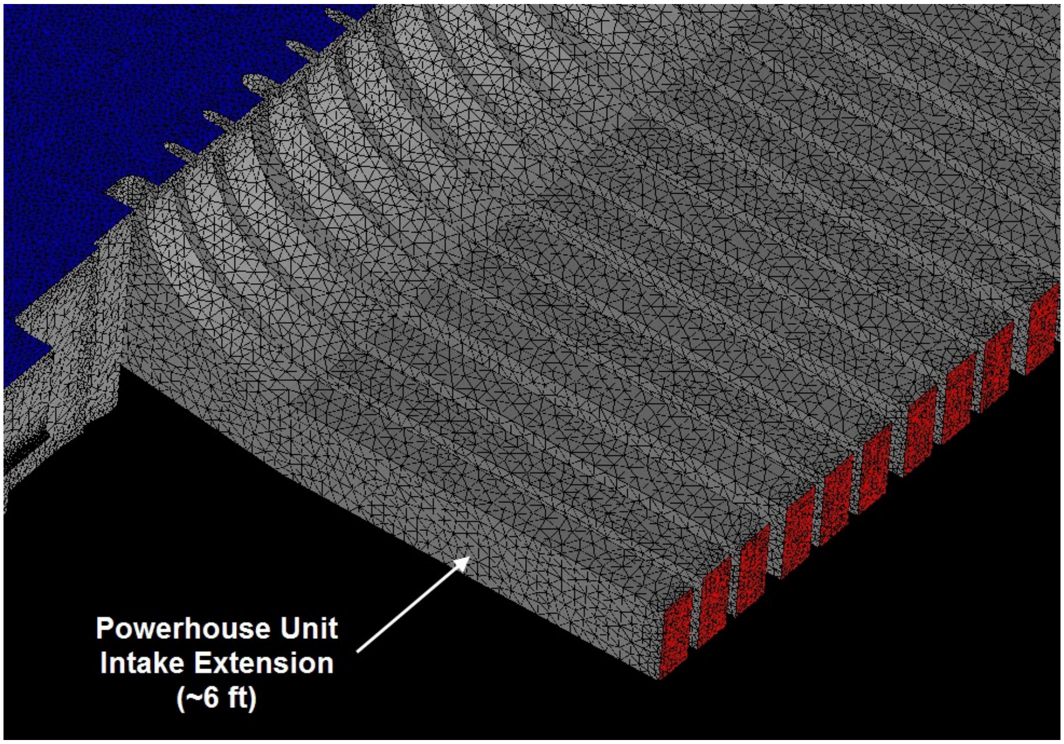

Figure 14. Mesh resolution detail at powerhouse unit intake extensions.

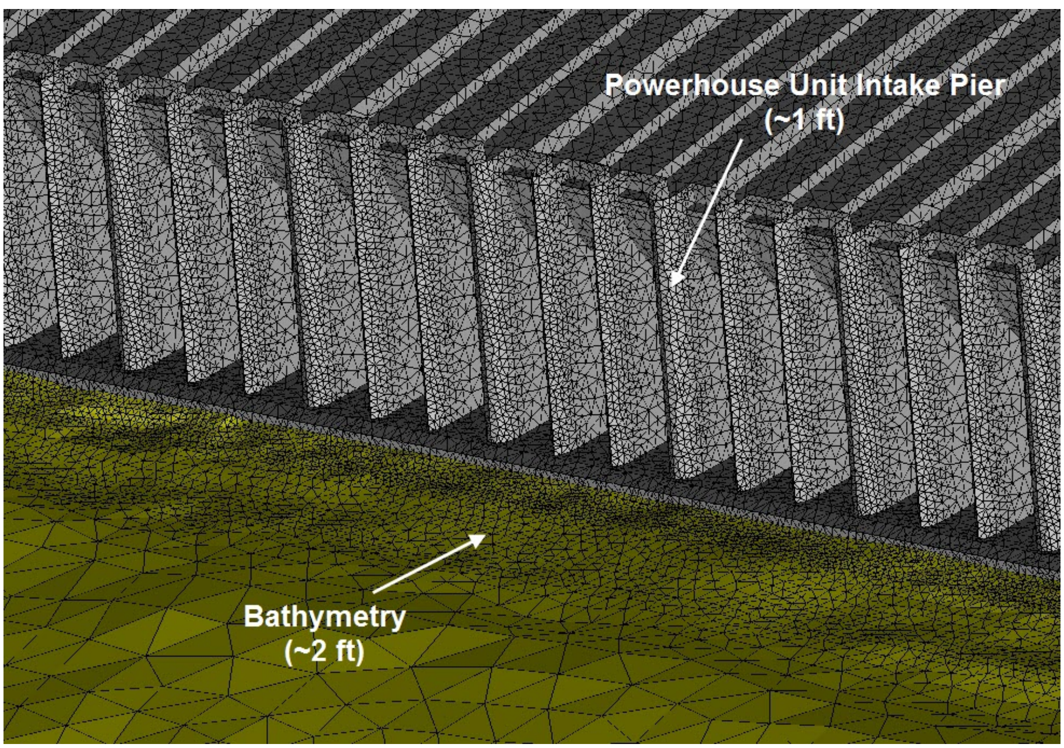

Figure 15. Surface mesh detail of powerhouse intakes and piers.

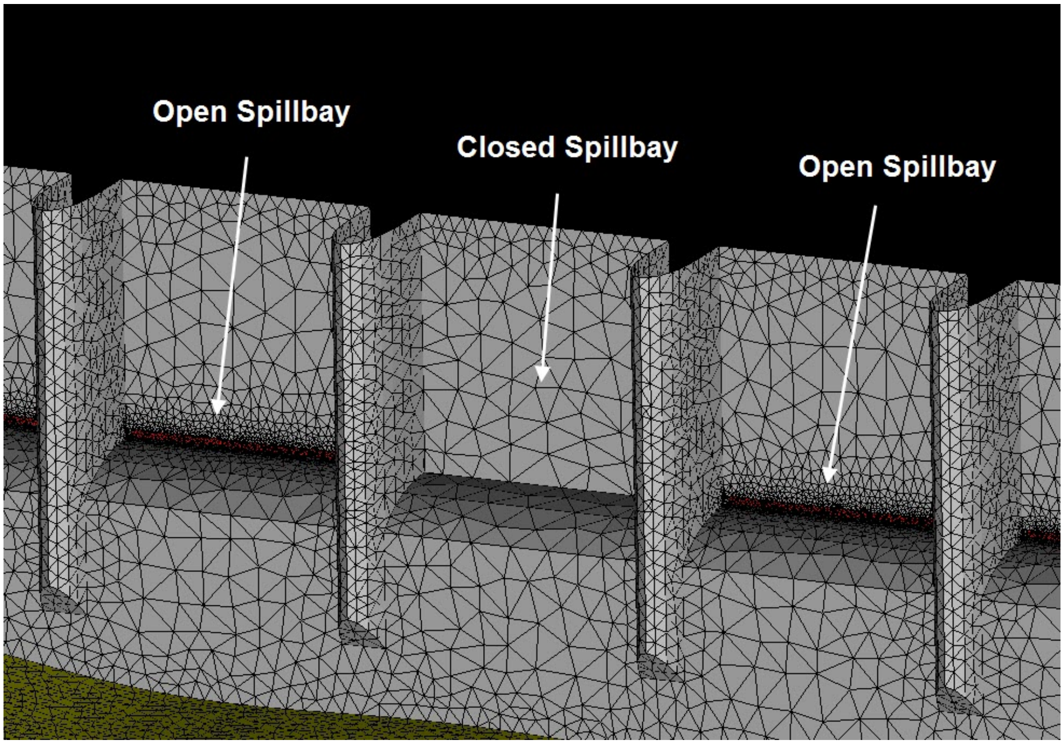

Figure 16. Surface mesh detail of open and closed spillbays.

Table 1. Mesh summary.

Operation(s)	Number of Nodes	Number of Cells
1, 2	1,214,234	6,210,574
3, 4	1,238,758	6,311,541
5, 6	1,249,932	6,371,751
7, 8	1,259,065	6,416,454
9, 10	1,249,377	6,389,903
11, 12	1,270,669	6,478,938
13, 14	1,285,686	6,545,118
15	1,295,958	6,599,595

4 Numerical Model Governing Equations

The flow through the McNary Dam forebay was simulated using the computational flow solver Fluent. The particular module chosen for all simulations used the Reynolds-Averaged Navier-Stokes (RANS) equations. The RANS equations are developed by decomposing each variable in the Navier-Stokes equation into mean and fluctuating portions. For example, the decomposition for the velocity u_i is:

$$u_i = \bar{u}_i + u_i'$$

where:

$\bar{u}_i$ = the mean velocity
u_i' = the fluctuating velocity
i = index indicating coordinate direction (1, 2, 3)

The RANS equations can then be written as:

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_i}(\rho u_i) = 0$$

and

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right)$$

where:

ρ = fluid density
p = pressure
μ = fluid viscosity
δ_{ij} = Kronecker's delta

The turbulent effects of the flow, included in the Reynolds stress $-\rho\overline{u_i' u_j'}$, were modeled with the standard k-ω turbulence closure model. In this model the turbulent kinetic energy k and the specific dissipation rate ω are determined using the following transport equations:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_k \frac{\partial k}{\partial x_j}\right)+G_k-Y_k+S_k$$

and

$$\frac{\partial}{\partial t}(\rho \omega)+\frac{\partial}{\partial x_i}(\rho \omega u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_\omega \frac{\partial \omega}{\partial x_j}\right)+G_\omega-Y_\omega+S_\omega$$

where:

G_k = generation of turbulent kinetic energy due to mean velocity gradients
G_ω = generation of specific dissipation rate
Γ_k = effective diffusivity of the turbulent kinetic energy
Γ_ω = effective diffusivity of specific dissipation rate
Y_k = dissipation of the turbulent kinetic energy due to turbulence
Y_ω = dissipation of the specific dissipation rate due to turbulence
S_k = source term
S_ω = source term

Further details of the formulation of the k-ω turbulence model used in Fluent, including how all terms associated with the turbulent kinetic energy and the specific dissipation are calculated, can be found in the *Fluent Theory Guide* (2010).

5 Input Summary – Operations 1 and 2

Operations 1 and 2 used a river discharge of 300.13 kcfs. Spillbays 4, 6, 8, 9, 10, 12, 13, 14, and 19 were closed. The gate opening and discharge for each spillbay are listed in Table 2.

Table 2. Operations 1 and 2 gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	2.0	3.90
2	2.0	3.90
3	2.0	3.90
4	0.0	0.00
5	1.0	2.01
6	0.0	0.00
7	1.0	2.01
8	0.0	0.00
9	0.0	0.00
10	0.0	0.00
11	1.0	2.01
12	0.0	0.00
13	0.0	0.00
14	0.0	0.00
15	1.0	2.01
16	1.0	2.01
17	2.0	3.90
18	5.0	8.80
19	0.0	0.00
20	5.0	8.80
21	2.0	3.90
22	1.0	2.01

Powerhouse Units 5-12 were turned off in Operation 1, but in Operation 2 Units 2-10 were turned off. The powerhouse discharges for Operations 1 and 2 are listed in Table 3.

Table 3. Operations 1 and 2 powerhouse discharges.

Powerhouse Unit	Discharge (kcfs) - Operation 1	Discharge (kcfs) - Operation 2
1	8.33	8.53
2	8.33	0.00
3	8.33	0.00
4	8.33	0.00
5	0.00	0.00
6	0.00	0.00
7	0.00	0.00
8	0.00	0.00
9	0.00	0.00
10	0.00	0.00
11	0.00	8.53
12	0.00	8.53
13	8.33	12.20
14	8.33	12.20

6 Input Summary – Operations 3 and 4

Operations 3 and 4 used a river discharge of 149.22 kcfs. Spillbay gate 19 was closed. The gate opening and discharge for each spillbay are listed in Table 4.

Table 4. Operations 3 and 4 spillbay gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	2.5	4.75
2	2.0	3.90
3	3.0	5.57
4	1.0	2.01
5	1.0	2.01
6	1.0	2.01
7	2.0	3.90
8	1.0	2.01
9	1.0	2.01
10	1.0	2.01
11	2.0	3.90
12	1.0	2.01
13	1.0	2.01
14	1.0	2.01
15	1.0	2.01
16	1.0	2.01
17	2.5	4.75
18	5.0	8.80
19	0.0	0.00
20	5.0	8.80
21	2.0	3.90
22	2.0	3.90

Powerhouse Units 5-9 were off in Operation 3. Units 2-8 were off in Operation 4. The powerhouse discharges for Operations 3 and 4 are listed in Table 5.

Table 5. Operations 3 and 4 powerhouse discharges.

Powerhouse Unit	Discharge (kcfs) - Operation 3	Discharge (kcfs) - Operation 4
1	8.33	8.73
2	8.33	0.00
3	8.33	0.00
4	8.33	0.00
5	0.00	0.00
6	0.00	0.00
7	0.00	0.00
8	0.00	0.00
9	0.00	8.73
10	8.33	8.73
11	8.33	12.20
12	8.33	12.20
13	8.33	12.20
14	8.33	12.20

7 Input Summary – Operations 5 and 6

Operations 5 and 6 used a river discharge of 199.86 kcfs. All spillbays were open. The gate opening and discharge for each spillbay are listed in Table 6.

Table 6. Operations 5 and 6 spillbay gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	2.5	4.75
2	2.0	3.90
3	3.0	5.57
4	1.0	2.01
5	2.0	3.90
6	2.0	3.90
7	2.0	3.90
8	1.0	2.01
9	2.0	3.90
10	2.0	3.90
11	2.0	3.90
12	2.0	3.90
13	2.0	3.90
14	1.0	2.01
15	2.0	3.90
16	2.0	3.90
17	2.5	4.75
18	5.0	8.80
19	5.0	8.80
20	5.0	8.80
21	2.5	4.75
22	2.5	4.75

For Operation 5 Powerhouse Units 5 and 6 were off. In Operation 6 Units 2-6 were off. The powerhouse discharges for Operations 5 and 6 are listed in Table 7.

Table 7. Operations 5 and 6 powerhouse discharges.

Powerhouse Unit	Discharge (kcfs) - Operation 5	Discharge (kcfs) - Operation 6
1	8.33	8.93
2	8.33	0.00
3	8.33	0.00
4	8.33	0.00
5	0.00	0.00
6	0.00	0.00
7	8.33	8.93
8	8.33	8.93
9	8.33	12.20
10	8.33	12.20
11	8.33	12.20
12	8.33	12.20
13	8.33	12.20
14	8.33	12.20

8 Input Summary – Operations 7 and 8

Operations 7 and 8 had a river discharge of 251.70 kcfs. All spillbays were open. The gate opening and discharge for each spillbay is listed in Table 8.

Table 8. Operations 7 and 8 spillbay gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	2.5	4.75
2	2.5	4.75
3	4.0	7.20
4	2.5	4.75
5	3.0	5.57
6	2.5	4.75
7	3.0	5.57
8	2.5	4.75
9	3.0	5.57
10	2.5	4.75
11	3.0	5.57
12	2.5	4.75
13	3.0	5.57
14	2.5	4.75
15	2.5	4.75
16	2.5	4.75
17	3.5	6.40
18	5.0	8.80
19	5.0	8.80
20	5.0	8.80
21	3.0	5.57
22	2.5	4.75

All powerhouse units were on for Operation 7, but in Operation 8 Units 2, 3, and 4 were off. The powerhouse discharges for Operations 7 and 8 are listed in Table 9.

Table 9. Operations 7 and 8 powerhouse discharges.

Powerhouse Unit	Discharge (kcfs) - Operation 7	Discharge (kcfs) - Operation 8
1	9.00	8.10
2	9.00	0.00
3	9.00	0.00
4	9.00	0.00
5	9.00	8.10
6	9.00	12.20
7	9.00	12.20
8	9.00	12.20
9	9.00	12.20
10	9.00	12.20
11	9.00	12.20
12	9.00	12.20
13	9.00	12.20
14	9.00	12.20

9 Input Summary – Operations 9 and 10

Operations 9 and 10 used a river discharge of 150.87 kcfs. Spillbays 1-8 and 12 were closed. Temporary spillway weirs were employed on Spillbays 19 and 20. The gate opening and discharge for each spillbay are listed in Table 10.

Table 10. Operations 9 and 10 spillbay gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	0.0	0.00
2	0.0	0.00
3	0.0	0.00
4	0.0	0.00
5	0.0	0.00
6	0.0	0.00
7	0.0	0.00
8	0.0	0.00
9	2.0	3.90
10	2.0	3.90
11	2.0	3.90
12	0.0	0.00
13	2.0	3.90
14	2.0	3.90
15	2.0	3.90
16	2.0	3.90
17	2.0	3.90
18	2.0	3.90
19	TSW	9.01
20	TSW	9.01
21	2.0	3.90
22	2.0	3.90

Powerhouse Units 5-7 were off for Operation 9. Powerhouse Units 2-7 were off in Operation 10. The powerhouse discharges for Operations 9 and 10 are listed in Table 11.

Table 11. Operations 9 and 10 powerhouse discharges.

Powerhouse Unit	Discharge (kcfs) - Operation 9	Discharge (kcfs) - Operation 10
1	8.18	8.4
2	8.18	0.0
3	8.18	0.0
4	8.18	0.0
5	0.00	0.0
6	0.00	0.0
7	0.00	0.0
8	8.18	8.4
9	8.18	12.2
10	8.18	12.2
11	8.18	12.2
12	8.18	12.2
13	8.18	12.2
14	8.18	12.2

10 Input Summary – Operations 11 and 12

Operations 11 and 12 used a river discharge of 200.05 kcfs. Spillbays 4, 8, and 12 were closed, and Spillbays 19 and 20 employed temporary spillway weirs. The gate opening and discharge for each spillbay are listed in Table 12.

Table 12. Operatiions 11 and 12 spillbay gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	2.5	4.75
2	2.0	3.90
3	3.5	6.40
4	0.0	0.00
5	2.0	3.90
6	1.0	2.01
7	2.0	3.90
8	0.0	0.00
9	2.0	3.90
10	1.0	2.01
11	2.0	3.90
12	0.0	0.00
13	2.0	3.90
14	1.0	2.01
15	2.0	3.90
16	1.0	2.01
17	2.0	3.90
18	2.0	3.90
19	TSW	9.01
20	TSW	9.01
21	2.0	3.90
22	2.0	3.90

All powerhouse units were turned on in Operation 11. Units 2, 3, and 4 were off in Operation 12. The powerhouse discharges for both operations are listed in Table 13.

Table 13. Operations 11 and 12 powerhouse discharges

Powerhouse Unit	Discharge (kcfs) - Operation 11	Discharge (kcfs) - Operation 12
1	8.57	8.65
2	8.57	0.00
3	8.57	0.00
4	8.57	0.00
5	8.57	8.65
6	8.57	8.65
7	8.57	8.65
8	8.57	12.20
9	8.57	12.20
10	8.57	12.20
11	8.57	12.20
12	8.57	12.20
13	8.57	12.20
14	8.57	12.20

11 Input Summary – Operations 13 and 14

A river discharge of 249.13 kcfs was used for Operations 13 and 14. All spillbays were open except Spillbays 19 and 20, which had temporary spillway weirs. The gate opening and discharge for each spillbay is listed in Table 14.

Table 14. Operations 13 and 14 spillbay gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	2.5	4.75
2	2.0	3.90
3	3.5	6.40
4	1.0	2.01
5	2.0	3.90
6	2.0	3.90
7	2.0	3.90
8	2.0	3.90
9	2.0	3.90
10	2.0	3.90
11	2.0	3.90
12	2.0	3.90
13	2.0	3.90
14	2.0	3.90
15	2.0	3.90
16	2.0	3.90
17	2.0	3.90
18	2.0	3.90
19	TSW	9.01
20	TSW	9.01
21	2.5	4.75
22	2.5	4.75

All powerhouse units were on in Operation 13. Powerhouse Unit 2 was off in Operation 14. The powerhouse discharges for Operations 13 and 14 are listed in Table 15.

Table 15. Operations 13 and 14 powerhouse discharges

Powerhouse Unit	Discharge (kcfs) - Operation 13	Discharge (kcfs) - Operation 14
1	10.71	9.33
2	10.71	0.00
3	10.71	9.33
4	10.71	9.33
5	10.71	12.20
6	10.71	12.20
7	10.71	12.20
8	10.71	12.20
9	10.71	12.20
10	10.71	12.20
11	10.71	12.20
12	10.71	12.20
13	10.71	12.20
14	10.71	12.20

12 Input Summary – Operation 15

Operation 15 used a river discharge of 149.22 kcfs. All spillbays were open, except Spillbays 19 and 20, which had temporary spillway weirs. The gate opening and discharge for each spillbay is listed in Table 16.

Table 16. Operations 15 spillbay gate openings and discharges.

Spillbay	Gate Opening (ft)	Discharge (kcfs)
1	2.5	4.75
2	2.5	4.75
3	5.0	8.80
4	3.0	5.57
5	3.0	5.57
6	3.0	5.57
7	3.0	5.57
8	3.0	5.57
9	3.0	5.57
10	3.0	5.57
11	3.0	5.57
12	3.0	5.57
13	3.0	5.57
14	2.5	4.75
15	3.0	5.57
16	3.0	5.57
17	3.0	5.57
18	3.0	5.57
19	TSW	9.01
20	TSW	9.01
21	3.0	5.57
22	2.5	4.75

All powerhouse units were on for Operation 15. The discharges for each powerhouse unit are listed in Table 17.

Table 17. Operation 15 powerhouse discharges.

Powerhouse Unit	Discharge (kcfs) - Operation 15
1	12.20
2	12.20
3	12.20
4	12.20
5	12.20
6	12.20
7	12.20
8	12.20
9	12.20
10	12.20
11	12.20
12	12.20
13	12.20
14	12.20

13 Boundary Conditions

Each flow operation was modeled with a fixed-lid water surface under steady-state conditions using the known water surface profile as the vertical limit of the flow domain. The bathymetry and structure were assigned a no-slip condition, so the velocity at each of these boundaries is zero. The sides of the flow domain, which trimmed the shallow regions of the river, were assigned a slip condition, so the shear stress at each of these boundaries is zero. The water surface was also treated as a slip boundary.

All discharges for the model were provided by NWW. The model discharge was specified as a constant inflow velocity across the upstream boundary, 5000 ft upstream of dam. The flux was specified at each outflow boundary (spillbays and powerhouse unit) as a ratio of the river discharge. Physical model studies have shown that the distribution of flow into a powerhouse unit is not uniform. Therefore, the flow through each powerhouse unit was divided among the three intakes using the following ratios: 0.361 for Inlet A, 0.350 for Inlet B, and 0.289 for Inlet C. These ratios were suggested by Davidson (2011) and have commonly been used on model studies of U.S. Corps of Engineers projects on the Columbia-Snake River System. The actual discharge values used in each simulation are included in the Input Summary sections.

14 Simulations

Each flow operation was modeled with the steady-state flow model in Ansys Fluent. The standard k-ω turbulence model with the default Fluent parameters was used for all simulations. The flow solver options used for each operation are given in Table 18.

Table 18. Simulation parameters.

Parameter	Choice
Pressure-Velocity Coupling	Coupled
Spatial Discretization – Gradient	Green-Gauss Node Based
Spatial Discretization – Pressure	Body-Force Weighted
Spatial Discretization – Momentum	Second Order Upwind
Spatial Discretization – Turbulent Kinetic Energy	Second Order Upwind
Spatial Discretization – Turbulent Dissipation Rate	First Order Upwind

15 Results

Contour plots were generated for each operation to illustrate the flows near the structure. The flow quantities of interest – the velocity magnitude, the acceleration magnitude, and the strain rate – were generated from the original Fluent solution files. The velocity magnitude is defined as:

$$V = \sqrt{u^2 + v^2 + w^2}$$

where:

u = x-component of the velocity
v = y-component of the velocity
w = z-component of velocity

The acceleration magnitude is defined as:

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

where a_x, a_y, and a_z are the acceleration components. For steady flow these components are defined as:

$$a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}$$

$$a_y = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}$$

$$a_z = u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}$$

The strain rate is defined as:

$$S = \left|\frac{\partial u}{\partial x}\right| + \left|\frac{\partial u}{\partial y}\right| + \left|\frac{\partial u}{\partial z}\right| + \left|\frac{\partial v}{\partial x}\right| + \left|\frac{\partial v}{\partial y}\right| + \left|\frac{\partial v}{\partial z}\right| + \left|\frac{\partial w}{\partial x}\right| + \left|\frac{\partial w}{\partial y}\right| + \left|\frac{\partial w}{\partial z}\right|$$

Plan view contour plots, at 5-ft increments of depth and extending about 1000 ft upstream of the structure, were generated for each operation. Elevation view contour plots of the areas near each powerhouse unit and spillbay were also provided for each operation to show the vertical variation in the flow variables of interest. These views are along the centerline of each powerhouse unit and spillbay and extend about 85 ft upstream of the face of the powerhouse intakes. Figures showing streamlines initiated at the inflow boundary were created to show the three-dimensional aspects of the flow. In these plots, the streamlines are colored by velocity magnitude. An overall view of the streamlines was created in addition to views showing more closely the streamlines near the powerhouse and spillway. One hundred thirty-one figures were generated for each flow operation and sent to NWW electronically. Examples of each type of figure produced during this study are shown in Figures 17-32.

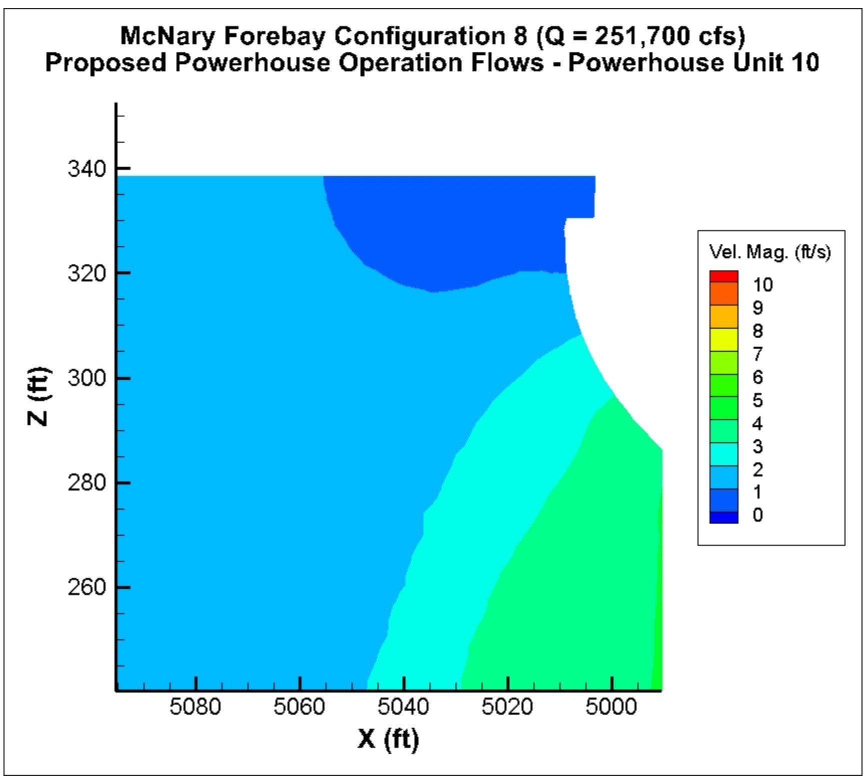

Figure 17. Elevation view plot example – velocity magnitudes at a powerhouse.

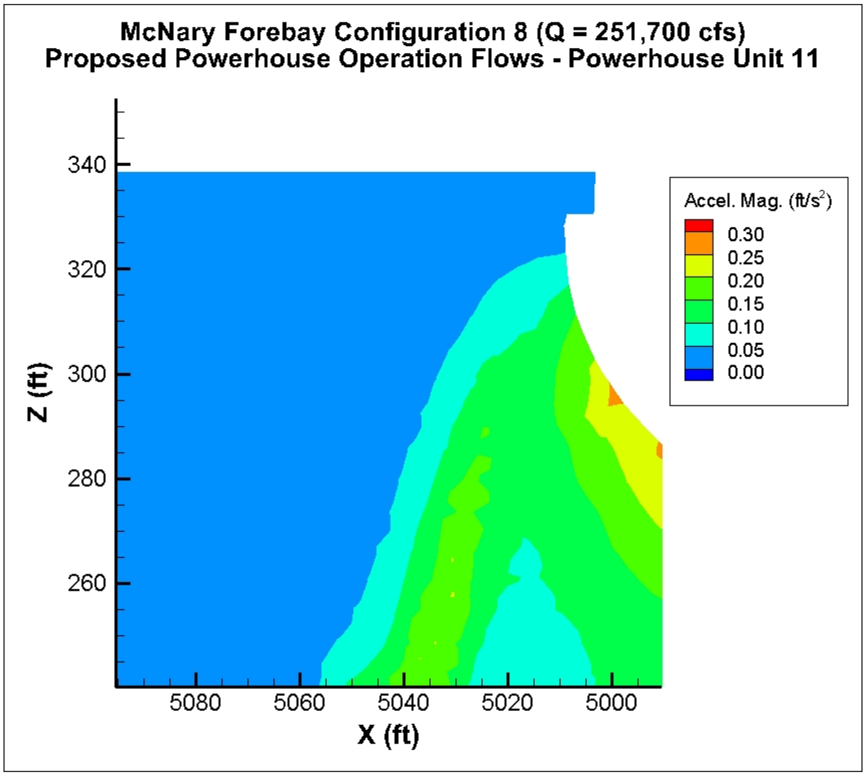

Figure 18. Elevation view plot example - acceleration magnitudes at a powerhouse.

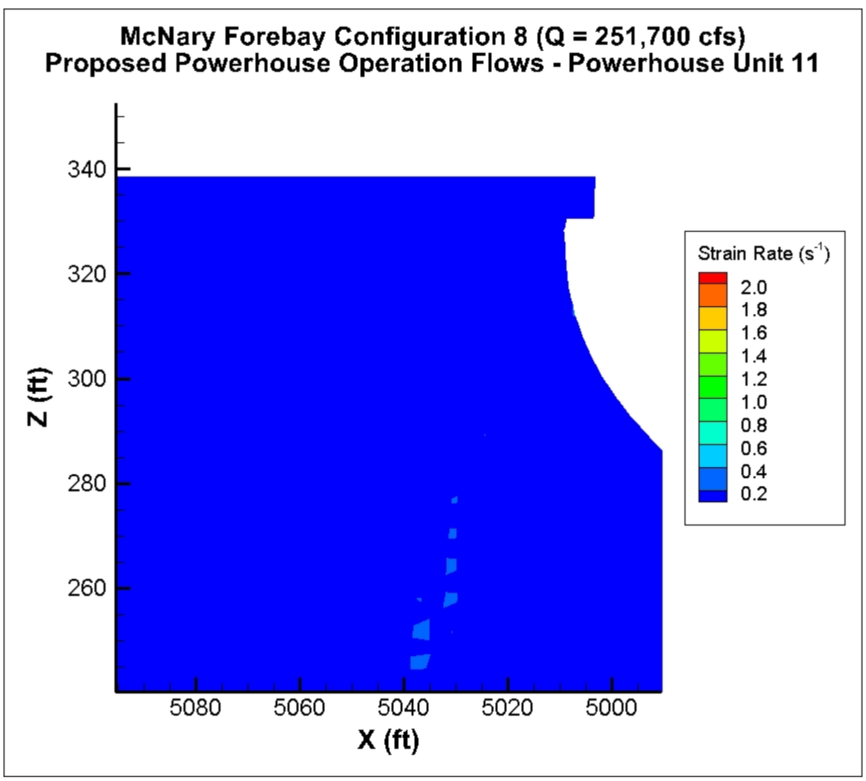

Figure 19. Elevation view plot example – strain rates at a powerhouse.

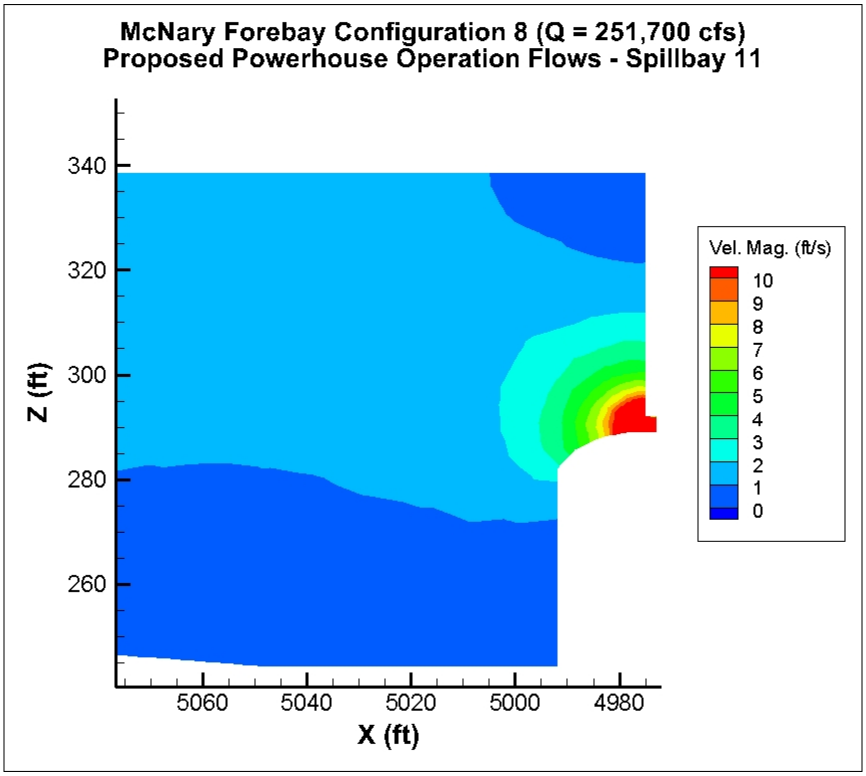

Figure 20. Elevation view plot example – velocity magnitudes at a spillbay.

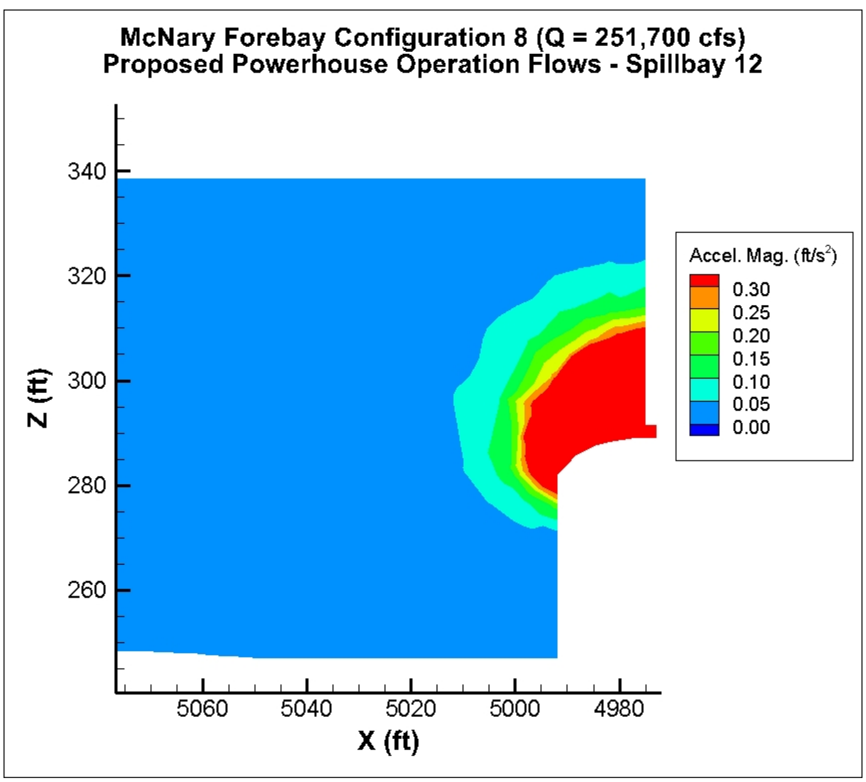

Figure 21. Elevation view plot example – acceleration magnitudes at a spillbay.

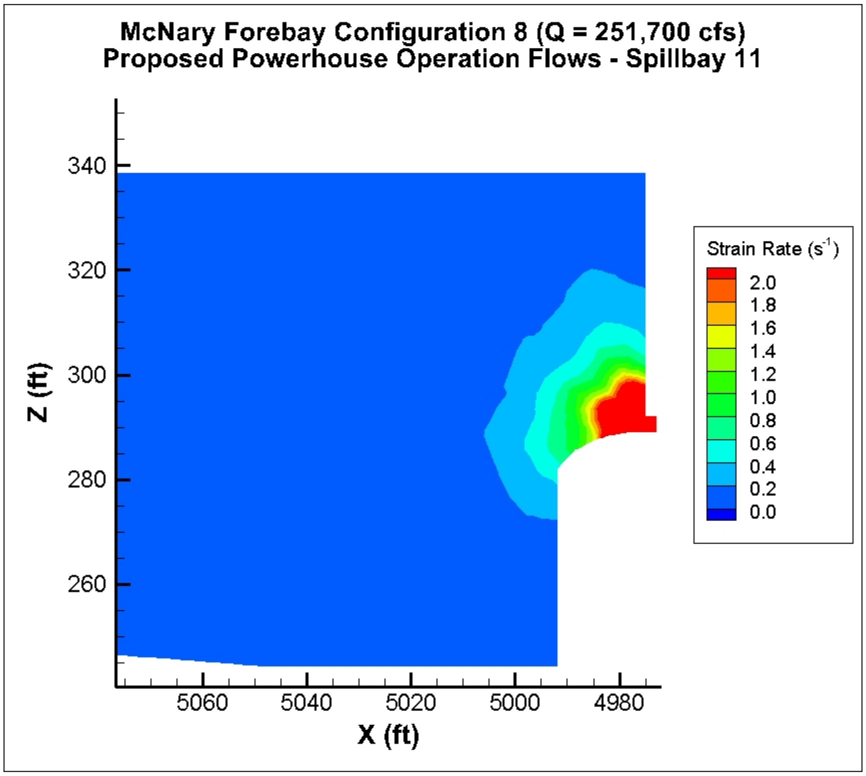

Figure 22. Elevation view plot example – strain rates at a spillbay.

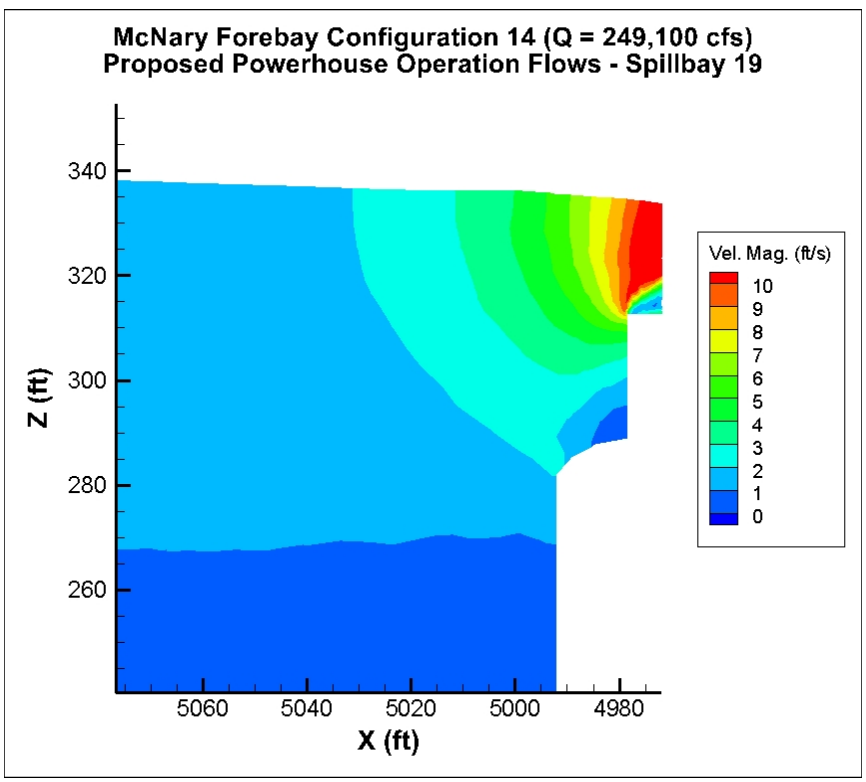

Figure 23. Elevation view plot example – velocity magnitudes at a spillbay with a TSW.

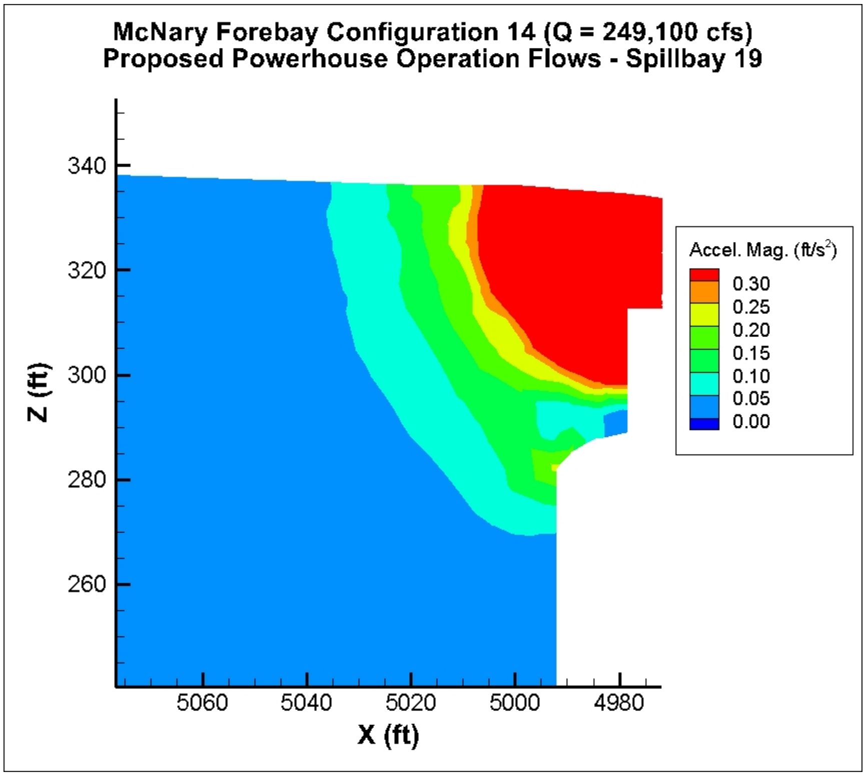

Figure 24. Elevation view plot example – acceleration magnitudes at a spillbay with a TSW.

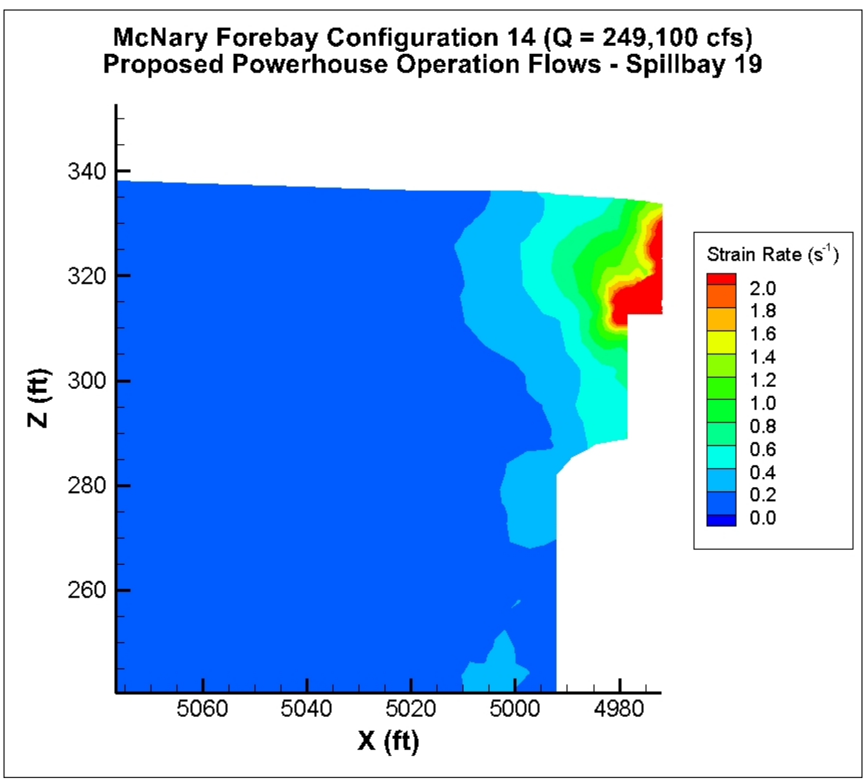

Figure 25. Elevation view plot example – strain rate at a spillbay with a TSW.

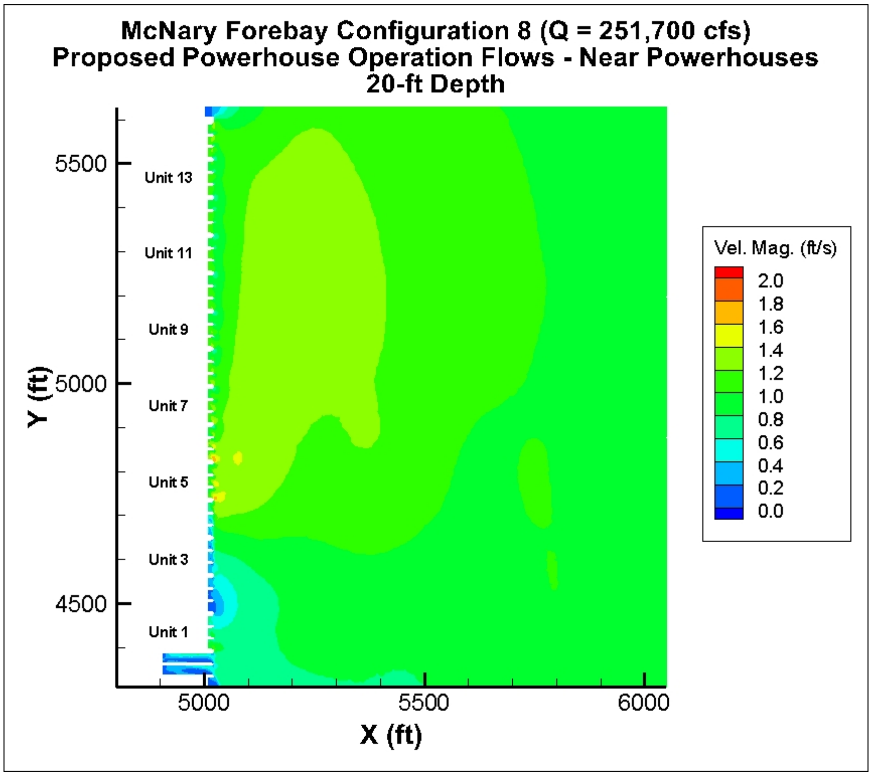

Figure 26. Plan view plot example – velocity magnitudes near the powerhouses.

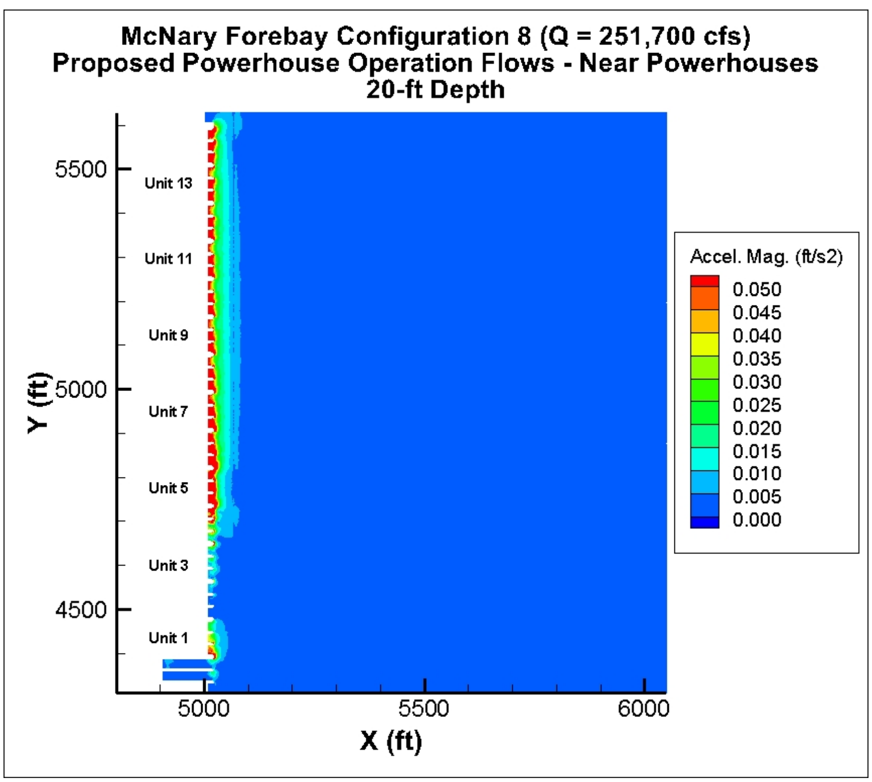

Figure 27. Plan view plot example – acceleration magnitudes near the powerhouses.

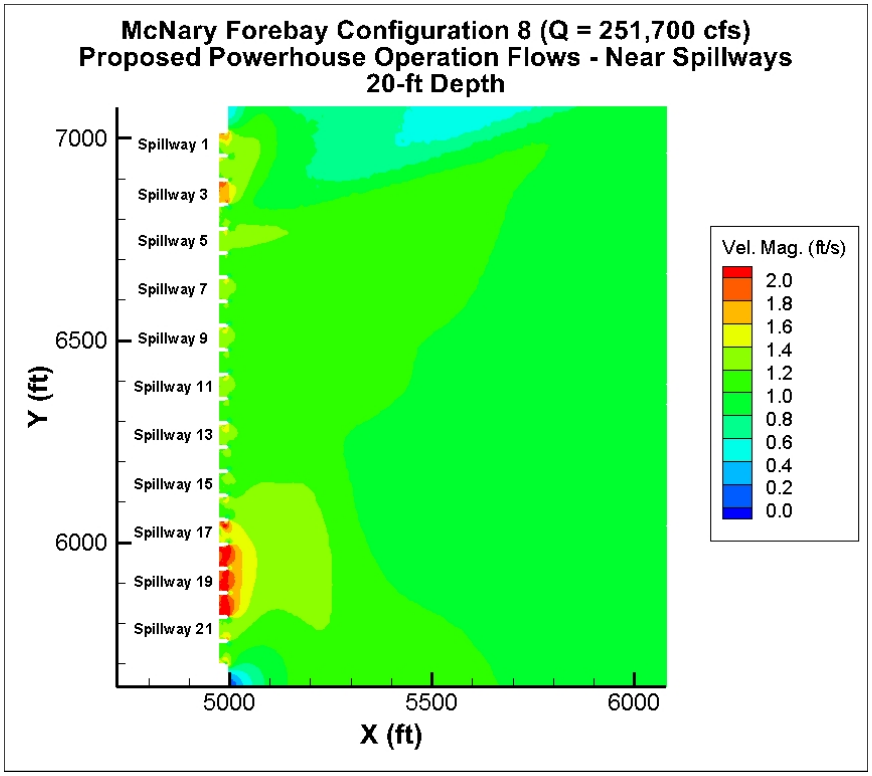

Figure 28. Plan view plot example – velocity magnitudes near the spillbays.

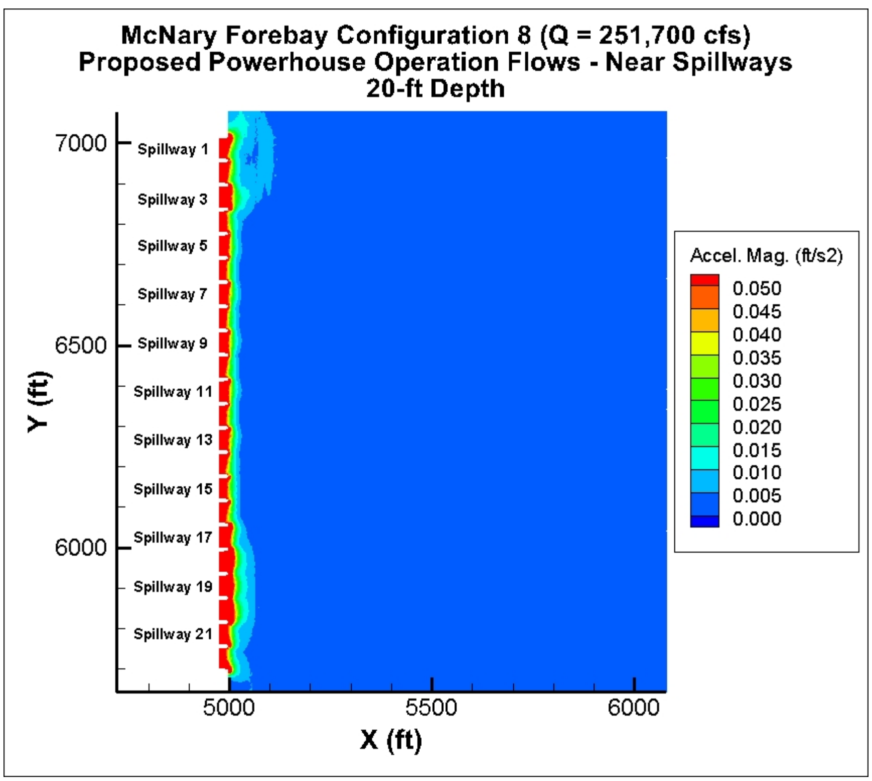

Figure 29. Plan view plot example – acceleration magnitudes near the spillbays.

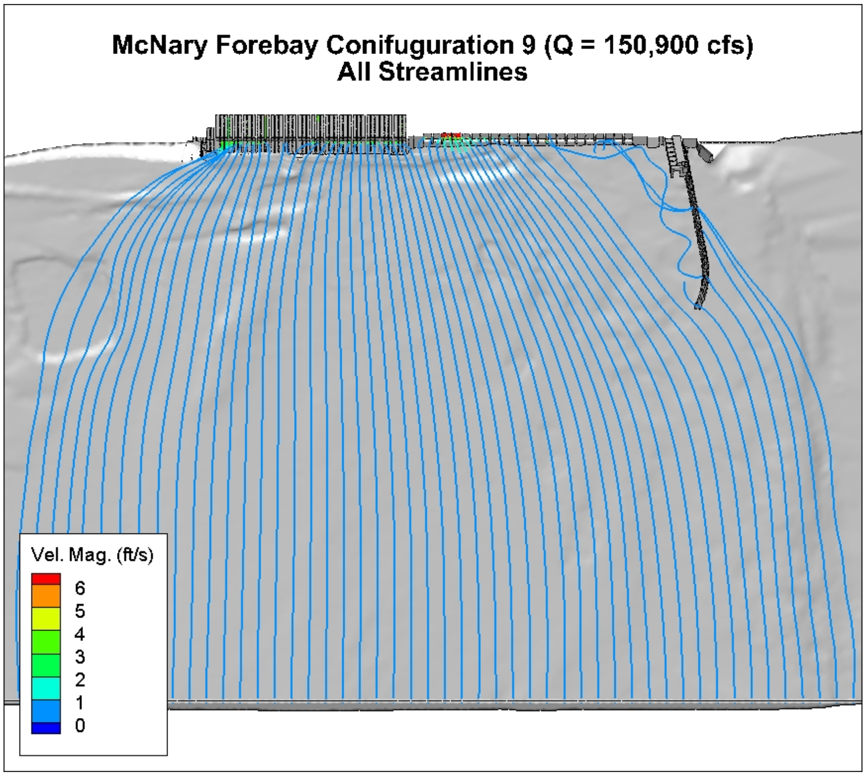

Figure 30. Streamlines in the forebay.

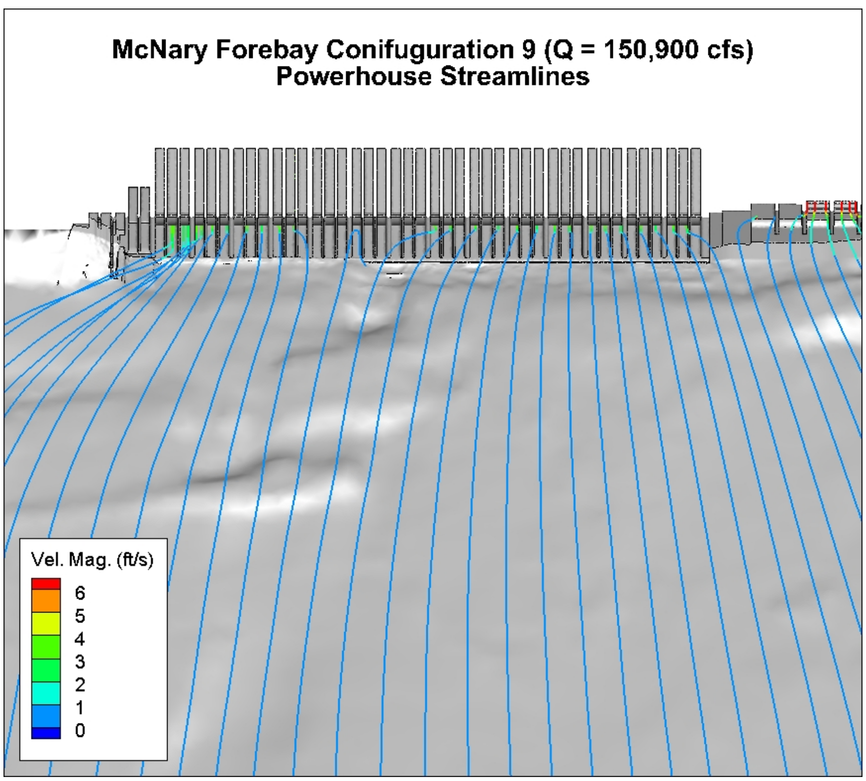

Figure 31. Streamlines near the powerhouse.

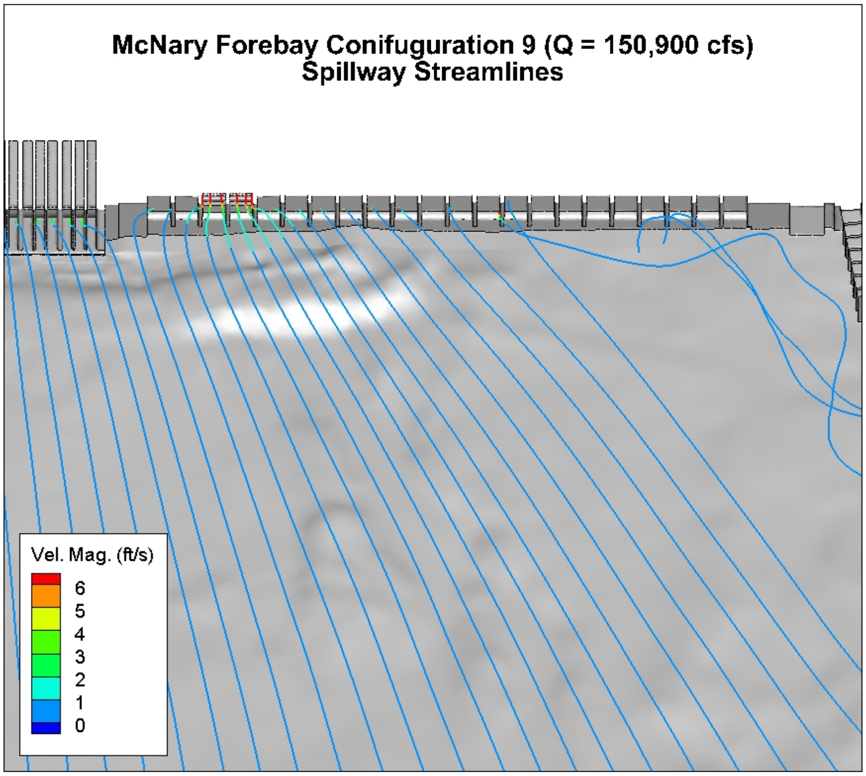

Figure 32. Streamlines near the spillway.

16 Files Supplied to NWW

The mesh and flow solution files for each operation were provided to NWW. The naming convention and description of these files are listed in Table 19.

Table 19. File naming conventions and descriptions – mesh and flow solution.

File Naming Convention[1]	File Description
mfc*.msh	Mesh file including the nodes, cell, and boundary condition types
mfc*_500.cas	Fluent simulation setup file containing the boundary conditions, operating conditions, fluid properties, turbulence model, and solver parameters used in the simulation
mfc*_500.dat	Fluent simulation data file including all variables calculated during the simulation
mfc*_raw_solution.plt	Binary Tecplot data file containing the flow variables used during post-processing written directly from the Fluent output files (.cas and .dat)
mfc*_processed_solution.lay	Tecplot layout file used to generate all the elevation and plan view figures of the flow solution
mfc*_processed_solution.plt	Binary Tecplot data file containing all flow variables (in both SI and English units) used to generate the elevation and plan view figures of the flow solution

The files associated with the figures described in the Results section were also provided to NWW electronically. The naming convention and description of these files are listed in Table 20.

Each picture file (.jpg) has a corresponding Tecplot style file (.sty) that was used with the Tecplot macros to generate each figure.

[1] * - the configuration number (1-15)

Table 20. File naming conventions and descriptions – figures and Tecplot macros.

Naming Convention[1,2]	Description
mfc* %-ft Depth Near Powerhouse Velocity Magnitudes.jpg	The velocity magnitude contours in the area immediately upstream of the powerhouses
mfc*%-ft Depth Near Powerhouse Acceleration Magnitudes. jpg	The acceleration magnitude contours in the area immediately upstream of the powerhouse intakes
mfc* %-ft Depth Near Spillway Velocity Magnitudes.sty	The velocity magnitude contours in the area immediately upstream of the spillway
mfc*%-ft Depth Near Spillway Acceleration Magnitudes.sty	The acceleration magnitude contours in the area immediately upstream of the spillway
mfc* Powerhouse # Velocity Magnitudes. jpg	The velocity magnitude contours in the area immediately upstream of a particular powerhouse unit intake
mfc* Powerhouse # Acceleration Magnitudes. jpg	The acceleration magnitude contours in the area immediately upstream of a particular powerhouse intake
mfc* Powerhouse # Strain Rates. jpg	The strain rate contours in the area immediately upstream of a particular powerhouse unit intake
mfc* Spillbay # Velocity Magnitudes. jpg	The velocity magnitude contours in the area immediately upstream of a particular spillbay
mfc* Spillbay # Acceleration Magnitudes. jpg	The acceleration magnitude contours in the area immediately upstream of a particular spillbay
mfc* Spillbay # Strain Rates. jpg	The strain rate magnitude contours in the area immediately upstream of a particular spillbay
mfc*_import_fluent_save_plt.mcr	Tecplot macro that imports the Fluent .cas and .dat files from a completed simulation and writes the required flow variables (node coordinates, pressure, velocity components, velocity gradient components, and turbulent kinetic energy) for post-processing to a binary Tecplot data file (.plt)
mfc*_equations_slices.mcr	Tecplot macro that calculates the velocity magnitude, acceleration magnitude, and velocity magnitude at each node in the flow field, and creates the slices used in each 2D flow figure
mfc*_output_figures.mcr	Tecplot macro that uses each Tecplot style (.sty) file to generate each 2D flow figure

[1] % - the depth (5, 10, 15, 20, or 25)

[2] # - the spillbay or powerhouse unit number (1-22 for spillbays and 1-14 for powerhouse units)

17 Fish Behavior Modeling File Formatting

The Numerical Fish Surrogate (NFS) model will be used by ERDC-EL to model fish behavior. A utility (tec2telam) was developed to convert the flow solutions into a format appropriate for NFS. For each flow solution, a file containing certain flow information is required and is referred to as the "telam" file. The flow information required by the NFS model for each node in the flow field is pressure, velocity components, turbulent kinetic energy, strain rate, and the node number. Tec2telam uses the flow solution and the coordinates of the flux, no flux, and water surface nodes to assign the appropriate Node BC value for proper fish behavior modeling. A definition of Node BC is included in the ELAM manual (Goodwin 2010). All files associated with tec2elam are listed Table 21.

Table 21. File naming conventions and descriptions – fish behavior modeling.

File Naming Convention[1]	File Description
mfc*_domain.dat	Tecplot data file containing all flow variables required for fish behavior modeling for every node in the flow domain
mfc*_wsurf.dat	Tecplot data file containing the coordinates of the nodes that comprise the water surface of the flow domain
mfc*_flux.dat	Tecplot data file containing the coordinates of the nodes that lie on any flow domain flux boundary
mfc*_no_flux.dat	Tecplot data file containing the coordinates of the nodes that lie on any flow domain no flux boundary
mfc*_nodebc_id.txt	Text file containing the Node BC value assigned to each flux boundary in the flow domain
mfc*_telam.plt	Binary Tecplot file containing the variables used in the fish behavior modeling

[1] * - the configuration number (1-15)

References

Goodwin, R.A. 2010. ELAM Mesh Data Format Guide: Aquatic Systems Version 12.2.

Davidson, Bob. January 28, 2011. Personal email.

Fluent Theory Guide. November 2010. Release 13.0.

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14. ABSTRACT

The U.S. Army Corps of Engineers, Walla Walla District (NWW), requested that the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL) model the flow conditions of McNary Dam forebay. The different flows are produced by various powerhouse/spillbay operating conditions for certain river discharges. The flow conditions, powerhouse operation schedule, and spillbay opening geometry were provided by NWW. This report contains a description of the geometry, meshing, and the flow conditions.

The report also describes flow solutions obtained using the commercial flow code Fluent. Fifteen river discharge/powerhouse/spillbay operations were included in the analysis. Figures of the flow velocity, acceleration, and strain rate near each powerhouse unit and spillbay have been provided to NWW electronically.

15. SUBJECT TERMS

Fish behavior	McNary	Spillway
Hydraulics	Numerical modeling	Temporary spillway weir
	Powerhouse	Three-dimensional

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